



HALEY & ALDRICH, INC.
One Arizona Center
400 E. Van Buren St., Suite 545
Phoenix, AZ 85004
602.760.2450

MEMORANDUM

16 October 2020
File No. 132599-005

TO: Florence Copper Inc.
Brent Berg, General Manager

FROM: Haley & Aldrich, Inc.
Mark Nicholls, R.G.
Senior Hydrogeologist

SUBJECT: Test Plan, Annular Conductivity Device (ACD) Bench Scale Demonstration

Introduction

Florence Copper Inc. (Florence Copper) has proposed to install Annular Conductivity Devices (ACD) on all Class III wells to be constructed in conjunction with the planned commercial-scale In-Situ Copper Recovery (ISCR) operations at the Florence Copper Site. The application of the ACDs will include all of the proposed injection, recovery, observation, and perimeter wells. The purpose of the ACDs is to detect migration of injected fluid through a micro-annulus between the fiberglass well casing and the cement seal; and through the formation surrounding each ISCR well.

The ACDs will be installed on each fiberglass well casing and will be comprised of two stainless steel well casing centralizers, spaced 3 feet apart. The ACDs will be installed directly on the fiberglass well casing at the contact point between the cement seal and the well casing. This installation will facilitate monitoring of any micro-annulus that might form between the well casing and the cement seal. The ACD arms will be in contact with the formation at the borehole wall which will facilitate detection of electrical conductivity changes induced by fluid migration through the lower basin fill unit around the well. The ACDs will simultaneously monitor conductivity of fluids migrating through the micro-annulus and vertical excursion of injected fluid in the formation adjacent to the ACD.

The ACDs will be monitored by measuring the electrical resistivity between the two centralizers. Because the injected fluid is much more conductive than native groundwater, the ACDs will register a change in resistivity if injected fluid migrates to the area where the ACDs are installed. This monitoring method will be used to detect vertical migration of injected fluid during ISCR operations.

The U.S. Environmental Protection Agency has requested that Florence Copper demonstrate that the ACDs planned for installation at the ISCR wellfield are capable of detecting migration of injected solution.

Haley & Aldrich, Inc. has worked together with Geosystems Analysis to develop a bench scale test to evaluate the effectiveness of ACDs for monitoring migration of injected ISCR fluids. This document presents a test plan describing the materials, procedures, assumptions, and data collection methods incorporated into the bench scale test.

Objective

The objective of this test is to demonstrate the measurable difference in resistivity detected by the ACDs under freshwater saturation conditions and raffinate saturation conditions. These conditions simulate ambient conditions in which ACDs will be installed and simulate vertical migration of injected raffinate. The differential resistivity values observed under these laboratory conditions will serve as a basis for determining the presence of injected fluid at the ACD monitoring locations in the Florence Copper ISCR wellfield.

Test Description

The test will include the construction of four miniature ISCR wells equipped with ACDs installed at an appropriate spacing. The wells will be constructed in a tank using fiberglass well casing, stainless steel centralizers, Type V cement seals, and ACD cabling similar to that planned for the commercial-scale ISCR wells. Two tanks will be used, with two wells constructed in each tank. Two of the wells will be constructed with cast cement seals with no pre-established migration pathways, one of the wells will be constructed with cement seal with a planned defect that will create a migration pathway, and one well will be constructed with no cement seal as an experimental control.

Once the wells are constructed, the tanks will be filled with dry sand to support the wells. Resistivity measurements will be taken at each ACD over a period of 5 days to establish the baseline resistivity for the instrumentation and ACD assemblies under dry conditions.

After the instrumentation baseline has been established, the tanks will be filled with freshwater to a depth above the upper band of the upper ACD on each well. Resistivity measurements will be taken at each ACD over a period of 5 days to establish the resistivity signal under freshwater saturation conditions. This stage of the test will simulate the ACD signal generated under typical operational conditions with no vertical migration of injected fluid.

Following the 5-day freshwater data collection period, each tank will be flooded from the bottom with a synthetic raffinate fluid, displacing the freshwater. The raffinate will be composed of water and dissolved constituents, typically present in ISCR raffinate, and will reflect anticipated solution composition during operations. Once the freshwater has been fully displaced, resistivity measurements will be taken at each ACD over a period of 5 days to establish the resistivity signal under raffinate saturation conditions. This stage of the test will simulate the ACD signal generated by migration of injected fluid at an ACD location. The test will conclude at the end of the raffinate saturation stage, at which time the test apparatus will be dismantled.

Data collection will include resistivity measurements between each of the ACD pairs, water levels, and fluid conductivity. The 5-day measurement cycle will allow observation of equilibration effects resulting from filling the tanks.

The data generated from this test will include:

- Resistivity for ACD arms in contact with formation saturated with freshwater.
- Resistivity for ACD arms in contact with formation saturated in raffinate.
- Resistivity for ACD bands where the cement seal has been compromised.

These data will serve to demonstrate the measurable difference in resistivity signals generated from ACDs in native groundwater and ACDs contacted by injected solution and will serve as a basis for discerning migration of injected fluid at ACD locations. The observed differences in resistivity under the various conditions will demonstrate the effectiveness of the ACDs for monitoring purposes.

Test Plan

MATERIALS REQUIRED

The ACD demonstration will require the following materials:

1. Watertight tank(s) (two tanks planned)
2. 3-inch diameter fiberglass well casing (four pieces)
3. Slotted polyvinyl chloride (PVC) pipe for use as piezometer
4. Stainless steel well centralizers (eight total)
5. PVC insulated 12-gauge single strand copper wire
6. Cardboard monotube (three pieces for use as cement form)
7. Clean siliceous sand
8. Synthetic raffinate solution

INSTRUMENTATION

The instrumentation required includes:

1. Water level transducer (one in each tank)
2. Electrical conductivity sensor (installed at piezometer)
3. ACDs (two installed on each well casing)
4. Datalogger (to record resistivity between ACDs, water level data, and fluid conductivity data)

TEST PREPARATION

1. Prepare fiberglass well casing
 - a. Cut fiberglass casing to length.
 - b. Seal the lower end of each casing.
2. Prepare ACDs
 - a. Install wire leads on the stainless steel centralizers (one lead on each centralizer) and cut wire to length.
3. Install ACDs
 - a. Install wick/capillary tubing on one well casing to create a short circuit between the ACDs.
 - b. Install two ACDs on each fiberglass casing.
 - c. Install the lower ACD as close as possible to the bottom (sealed end) of the casing.
 - d. Install the upper ACD a minimum of 1 foot above the upper band of the lower ACD. Make sure the upper band of the upper ACD is below the planned level of sand in the tank.
 - e. Ensure that the ACD spacing on each casing is similar.
 - f. Label each wire lead as "Upper ACD" or "Lower ACD."
 - g. Secure the loose end of the wire leads to the top of the fiberglass casing.

ASSEMBLE MINIATURE WELLS

4. Prepare Well Casing for Assembly
 - a. Install lifting lugs on the top end of each casing.
 - b. Plug one end of each sonotube with plywood or equivalent material.
 - c. Secure the sonotubes in a vertical position on an appropriate surface, with the plugged end down.
 - d. Place three of the casing assemblies (including the one with the wick/capillary tubing) in the cardboard sonotubes.
 - e. Install casing assemblies with the capped end down, sitting on top of the bottom plug.
 - f. Verify that all wire leads are securely connected.
 - g. Mix and pour Type V cement filling the sonotubes from bottom to top with the casing in place.
 - i. Tap on or vibrate the sonotube to ensure that the cement settles appropriately.
 - ii. Allow cement to cure 48 hours or more.
 - iii. Cut the cardboard sonotube from top to bottom on two sides and remove it, while supporting the casing assembly with an appropriate lifting device.
 - iv. Inspect the centralizer arms and clean the tips where they are exposed.

PREPARE TANKS

5. Install Wells and Instrumentation in Tanks
 - a. Lift each casing/cement assembly into the tanks with an appropriate lifting device, and secure in a vertical position.
 - b. Label the top of each casing with information reflecting the casing name and cement seal condition.
 - c. Position the perforated PVC piezometer with instrumentation in the center of each tank and secure in a vertical position.
 - d. Fill the tank with dry sand to support the well assemblies. Fill to a level covering the upper band of the upper ACD on each casing.
 - e. Connect the data logger to the conductivity sensors, ACDs, and transducers.

A schematic diagram of a test tanks with wells and instrumentation installed is included in Figure 1.

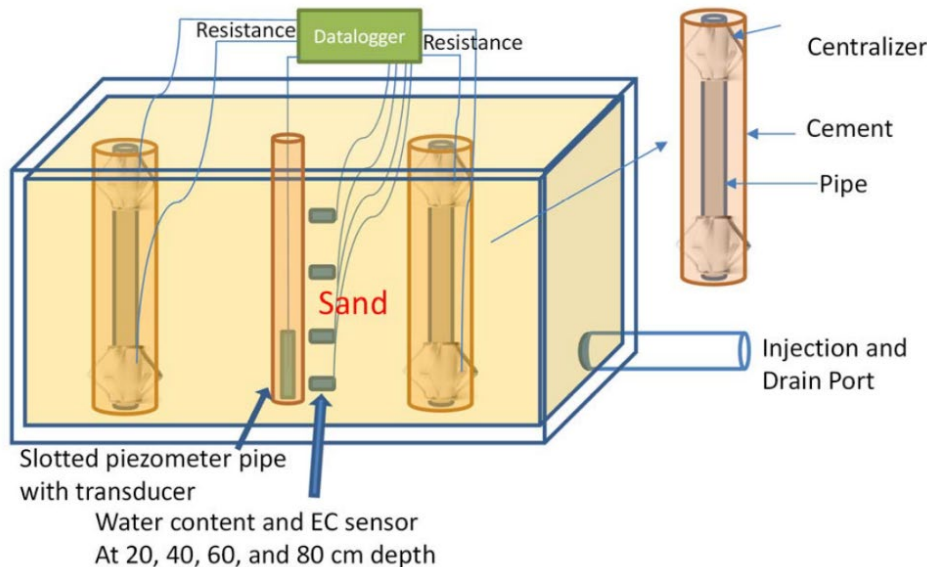


Figure 1. Schematic Diagram of Test Apparatus

TEST PROCEDURE AND DATA COLLECTION

Stage 1 (Dry)

1. This stage of the test is completed using tanks filled with sand with wells installed under dry conditions, no water or raffinate is to be added.
 - a. Record the resistance between the two ACDs on each fiberglass casing, hourly for 5 days.
 - b. Record water level and fluid conductivity values in each tank, hourly for 5 days.

Stage 2 (Saturated with Freshwater)

2. Fill the tanks with non-chlorinated freshwater, to a level just below the top of the sand.
 - a. Record the resistance between the two ACDs on each fiberglass casing, hourly for 5 days.
 - b. Record water level and fluid conductivity values in each tank, hourly for 5 days.

Stage 3 (Saturated with Raffinate)

3. Fully displace the freshwater by filling the tanks with raffinate from the bottom of each tank to a level just below the top of the sand.
4. Once daily for 5 days:
 - a. Record the resistance between the two ACDs on each fiberglass casing, hourly for 5 days.
 - b. Record water level and fluid conductivity values in each tank, hourly for 5 days.
5. Drain and dispose of the test apparatus.

DATA ANALYSIS

At the conclusion of the test, the time series resistivity data generated for each ACD pair will be evaluated relative to the water level and fluid conductivity. The distribution of each dataset will be evaluated graphically using time series plots and box plots to characterize the change in resistivity derived from the changing saturation and fluid composition during the test. Depending on the distribution of the data generated during the test, statistical analyses may be used to evaluate observed differences in resistivity under the various conditions.

REPORTING

At the conclusion of the test, a Technical Memorandum will be prepared summarizing the configuration, set-up, and execution of the ACD test. The Technical Memorandum will include a narrative description of the test procedures, data collection, and data analysis results. The memorandum will include the test data in tabular format and photographs of the test apparatus. The Technical Memorandum will also include a description of the rationale, scientific basis, data analysis, and the relationship between the bench scale test and the planned ISCR wellfield ACD installations.

Please contact Mark Nicholls (602-819-0913) with any question you may have regarding the content of this document.